NARRAGANSETT MARINE LABORATORY

GRADUATE SCHOOL OF OCEANOGRAPHY

UNIVERSITY OF RHODE ISLAND

Reference No. 63-2

ACOUSTICS PROJECT

The Relationship Between Wind Speed
And Shallow Water Ambient Noise

by

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Technical Report No. 8

Approved for Distribution

John A. Knauss

John A. Knauss, Dean

Office of Naval Research
Contract Nonr-396(04)
NR 385-205

January, 1963

K45

FOURTH INTERNATIONAL CONGRESS ON ACOUSTICS
COPENHAGEN 21.-28. AUGUST 1962

THE RELATIONSHIP BETWEEN WIND SPEED AND SHALLOW WATER AMBIENT NOISE

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During the period from October 1958 through September 1959, the University of Rhode Island, supported by the Office of Naval Research, made a systematic series of ambient noise spectrum determinations in the lower West Passage of Narragansett Bay, Rhode Island. This body of water extends in a north-south direction and, in the vicinity of the hydrophone installation, is approximately one mile in width. It is bounded on the west by the mainland and on the east by an island. The mid-channel depth is 40 - 50 feet.

The purposes of the measurement program were to study the characteristics of the ambient noise and to determine possible correlations between the noise and certain environmental factors, such as: wind speed, wind direction, wave height, rainfall, and tidal currents.

In order to accomplish this, a sampling schedule was devised which called for a total of 864 spectrum determinations over the course of a year. Readings were made each month during two weeks chosen at random within the month. During each of the two weeks, two days of the five weekdays and one of the two weekend days were selected at random. Further, each of the three sampling days was divided into six equally spaced hour groups, and two spectrum determinations were made within each of the hour groups at times chosen at random. Thus, the acoustic spectrum was measured twelve times per day, three days per week, two weeks per month. This resulted in seventy-two spectra per month.

The receiving system consisted of a Brush Type AX-58C hydrophone, with preamplifier, supported one foot above a silty-sand bottom in forty feet of water approximately 900 feet from the west shore of the bay. The signals from the hydrophone were amplified and frequency analysed by a Bruel and Kjaer Spectrum Analyser on a one-third octave basis and recorded by a B & K Graphic Level Recorder. The recorder was operated at a paper speed of 1 mm/sec and approximately 1.9 min. were required to scan the spectrum between 40 cps and 10 000 cps.

Calibration was accomplished by injecting a random noise signal into the hydrophone preamplifier and recording it, after it passed through the complete system, on the same paper tape as the sound spectrum. This procedure allowed the determination of the average spectrum levels associated with nineteen selected frequencies, distributed over the frequency band, to be made in under ten minutes.

Acoustic and environmental information were entered in IBM punch cards and processed with the aid of the Computation Centers at Brown University and the University of Rhode Island. Significant correlations between ambient noise and the environmental variables were found for wind speed, rainfall, and tidal currents.

The effect of wind on the sea surface in our locality is a complex one and no attempt has been made to present any correlations between ambient noise and sea state. Tidal currents influence the noise spectrum below 100 cps and are likewise omitted from this presentation.

This paper is concerned with some of the relationships between wind speed and ambient noise. Wind speed and direction measurements were obtained from a Bendix-Friez recording anemometer mounted fifteen feet above the water surface and approximately 900 feet from the hydrophone. The results to be presented are based on a total of 651 spectrum determinations. Of the original 864 spectra, 213 were excluded from the analyses because of the presence of rainfall or the presence of ship and biological noise.

Included in the data sample are wind speeds ranging from 0 mph to 29 mph. The distribution of wind speed observations is given in Table 1.

Table 1

Distribution of Observations at Various Wind Speeds

Wind Speed	No. of Obsvs.	Wind Speed	No. of Obsvs.	Wind Speed	No. of Obsvs.
0	56	10	60	20	7
1	27	11	24	21	9
2	35	12	26	22	5
3	39	13	10	24	5
4	58	14	12	25	5
5	31	15	14	27	1
6	59	16	20	29	2
7	32	17	8	Total	651
8	49	18	16		
9	33	19	8		

Unpublished studies conducted in deeper water by the Admiralty Research Laboratory, the U.S. Navy Electronics Laboratory, and the Canadian Naval Research Establishment indicate that the ambient sound pressure level may be linearly associated with the logarithm of the wind speed, for wind speeds exceeding certain threshold values. Our data show similar results.

The average spectrum level, corresponding to particular wind speed, was computed for each of the nineteen frequencies and plotted versus the logarithm of the wind speed. A typical plot for a given frequency shows that the levels associated with small wind speeds are essentially the same. At higher wind speeds, above a threshold value, the sound level increases in a linear fashion. The threshold value was determined from the graphs by eye, and a linear regression line was computed for the pressure points corresponding to the higher wind speeds. Table 2 summarizes the results.

Table 2

Summary of Regression and Correlation Statistics, including the Number of Observations, (n), beyond the Threshold Velocity (v_t); Correlation Coefficient (r); Slope of Line of Best Fit (b); y Intercept (a); Wind Speed (x) in Miles Per Hour

Frequency cps	n	v_t mph	r	b	a	Regression
40	-	-	.14NS	1.0	-25.5	log y = -25.5 + 1.0 log x
50	6	21	.77NS	25.9	-60.8	-60.8 + 25.9
60	6	21	.75NS	30.5	-68.7	-68.7 + 30.5
80	4	24	.48NS	21.7	-59.3	-59.3 + 21.7
100	17	20	.78NS	32.3	-74.5	-74.5 + 32.3
150	15	12	.86*	21.4	-57.8	-57.8 + 21.4
200	17	10	.93*	29.7	-66.9	66.9 + 29.7
300	19	8	.97*	28.3	-65.0	-65.0 + 28.3
400	20	7	.98*	30.2	-66.5	-66.5 + 30.2
500	21	6	.99*	30.2	-67.6	-67.6 + 30.2
600	21	6	.99*	31.1	-69.0	-69.0 + 31.1
800	21	6	.99*	31.2	-69.5	-69.5 + 31.2
1 000	21	6	*	30.0	-69.9	-69.9 + 30.0
1 500	20	7	.99*	28.4	-70.9	-70.9 + 28.4
2 000	20	7	*	29.5	-73.3	-73.3 + 29.5
3 000	19	8	.98*	30.6	-77.0	-77.0 + 30.6
5 000	19	8	.98*	28.6	-78.1	-78.1 + 28.6
7 000	18	9	.98*	27.3	-81.2	-81.2 + 27.3
10 000	18	9	.89*	20.8	-76.0	log y = -76.0 + 20.8 log x

NS = correlation not significantly different from 0.
* = correlation significantly different from 0.
y = average pressure (dynes/cm^2/cycle).

It will be noted that statistically non-significant correlations between sound pressure and wind speed were obtained for frequencies less than 150 cps. These results for shallow water are in conformity with the results of oceanic ambient studies reported by various laboratories [For example, see G.M. Wenz, J. Acoust. Soc. Am. 33, 64 - 74 (1961)].

It is also seen from Table 2 that noise levels are most sensitive to wind in the frequency range 500 cps - 1 000 cps, and that the maximum regression line slope occurs at 800 cps. The minimum threshold wind speed is 6 mph.

The influence of wind speed on the acoustic spectrum can also be shown by graphing average ambient noise spectrum levels associated with a given frequency for various wind speed groupings. Table 3 displays these results.

Table 3

Average Ambient Noise Spectrum Levels for Various Frequencies and Wind Speed Groups (Db re 1 dyne/cm^2/cycle)

Frequency cps	Wind Speed Groups (mph) 0 - 5	6 - 10	11 - 15	16 - 20	21 - 29
40	-25.4	-25.4	-25.5	-22.5	-19.5
50	-27.2	-26.3	-27.0	-24.3	-26.2
60	-29.5	-28.4	-29.0	-26.4	-27.7
80	-32.5	-31.5	-32.1	-31.0	-31.1
100	-33.8	-33.0	-33.3	-32.0	-31.4
150	-35.2	-35.0	-33.8	-32.5	-29.6
200	-36.6	-35.6	-34.1	-32.2	-27.6
300	-39.0	-37.8	-34.2	-32.2	-26.8
400	-40.6	-38.8	-33.7	-30.8	-27.0
500	-44.0	-40.2	-34.6	-32.1	-26.5
600	-45.1	-41.0	-34.9	-32.9	-26.8
800	-46.5	-41.8	-35.0	-32.9	-27.9
1 000	-47.9	-43.0	-36.5	-34.3	-29.4
1 500	-48.5	-44.4	-38.8	-36.8	-31.7
2 000	-49.1	-45.5	-40.3	-38.2	-33.3
3 000	-50.2	-47.1	-42.9	-41.8	-
5 000	-52.4	-49.7	-44.3	-44.3	-38.0
7 000	-53.9	-51.7	-48.9	-47.0	-41.5
10 000	-55.8	-54.9	-52.4	-51.0	-46.8

Spectrum level versus frequency graphs of these data are, in general, characterized by two or three regions. Between 40 cps and 100 cps, the data points lie within 3 db of one another for all wind speeds measured. The slope of this portion of the spectrum is approximately -7 db per octave. Above 100 cps, the curves diverge. For the 0 - 5 mph and the 6 - 10 mph groups, the trend from 100 cps to 10 000 cps is of the order of -3 to -4 db per octave. Characteristic of the 11 - 15 mph and the 16 - 20 mph curves is the plateau region which occurs between 100 cps and 800 cps. Beyond 800 cps, the slopes of these two curves are approximately -4.5 db per octave. The highest winds measured produced a convex-shaped curve in the 100 cps - 800 cps region, and a slope, beyond 800 cps, of between -4 to -5 db per octave.

These results do not differ appreciably from the Knudsen curves, [V.O. Knudsen, R.S. Alford, and J.W. Emling, J. Marine Research 7, 410 - 429 (1948)], except that the slopes of the lines for small wind speeds are 1 - 2 db less than those reported by Knudsen, et al.

In summary, data accumulated over a year's time have been presented which show the effect of wind speed on the average acoustic ambient noise spectrum for a shallow water location free of shipping, biological noise, and rainfall. The results which have been presented include winds without regard to their directions. Investigations of the effects of winds blowing with, against, or across the tidal currents show that the average spectra are only slightly influenced by the wind direction.